TECHNICAL MEMORANDUM NO. 8

A METEOROLOGICALLY DRIVEN WHEAT STRESS INDICATOR MODEL

CROP CONDITION ASSESSMENT DIVISION

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREIGN AGRICULTURAL SERVICE

HOUSTON, TEXAS

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A METEOROLOGICALLY DRIVEN WHEAT STRESS INDICATOR MODEL	FIRST ISSUE

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1. REASON FOR ISSUANCE

Document the development of a model capable of giving an early indication of actual or potential plant stress due to moisture and temperature.

2. COVERAGE

The moisture/temperature values which both stress and optimize the vigor of the wheat plant by specific growth stages are reviewed. A description of the model structure and stress parameters are set forth. Model output and preliminary results are discussed.

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METEOROLOGICALLY DRIVEN WHEAT STRESS INDICATOR MODEL

PART 1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this Technical Memorandum is to document a wheat condition model that detects plant stress due to moisture deficiency and adverse temperatures and gives information on potential impact. A brief synposis of the climatic stress process on wheat at different growth stages is also given.

1.2 SITUATION

A major task of the Crop Condition Assessment Division, Foreign Agricultural Service, is to detect and assess adverse conditions that affect a crop's growth and production. Of major importance is moisture stress that occurs in wheat. To support this activity a moisture and temperature stress model was developed to alert a crop analyst of a potential problem area. The model utilizes meteorological data because it is generally available much sooner than Landsat data, and provides daily data versus the eighteen day interval data from Landsat. This model eliminates the necessity of spending time and resources in analyzing data over all wheat areas and allows these resources to concentrate on areas which the model indicates have high probability that stress is occurring or is likely to occur. After a potential stress area has been identified, an analyst can assess the condition using meteorological, Landsat, and ancillary data. This model is not intended as a stand-alone system, but rather, an indicator to a crop analyst to initiate an investigation of the area.

The CCAD mission of alert analysis requires a quick response system and will sacrifice exact quantative results to meet their response requirement. A subjective estimate, if timely, which provides information in general terms such as better or worse than last year and an approximate percentage is very useful in assessing an alert situation. As research provides better tools, it is believed that these subjective estimates can be made quantitatively accurate.

1.3 BACKGROUND

Wheat, during its growth cycle, can be subjected to many adverse factors by nature which will affect the yield, quality and may even destroy the plant. Some of these factors can be detected by use of meteorological hazard models. A good example of such models are yield models and winterkill models (TM No. 5 - A Meteorological Model to Aid in the Detection of Winterkill, January 24, 1979) which indicates potential destruction of the plant. The CCAD of FAS requires information on the condition of wheat, both winter and spring varieties, over various parts of the world. This evaluation of wheat production is not necessarily quantative, but more of a subjective nature. Inventories that generate a quantative estimate of production in bushels per acre over large areas are extremely expensive and slow in response.

The wheat plant stress model is an indicator model that alerts an area analyst of possible or probable moisture and temperature stress with potential for affecting the well being of the plant (yield). It does not predict events nor does it attempt to impact them. It only provides information that indicates conditions or problems have occurred within a prescribed geographic area.

The crop analyst must use other information such as Landsat data, historical data, intelligence reports from embassies or news from the wire services in addition to his personal knowledge to determine if the condition truly exists. If the condition exists then the areal extent and potential impact must be assessed. The principal function of the model is to filter information that is outside the normal range and to alert the crop analyst of the presence of potentially adverse conditions.

1.4 REFERENCES

Robertson, G.W., 1968. A Biometerological Time Scale for a Cereal Crop Involving Day and Night Temperatures and Photoperiod. Intern J. Biometeor. 12:191-223

Prutskou, F.M., 1973. Winter Wheat. Joint Publication Research Service, Arlington, Virginia. U.S. Department of Commerce, National Technical Information Service. JPRS-60652

Kulik, M.S. and V.V. Senekhchekov. 1966. Lectures on Agricultural Meteorology. U.S. Department of Commerce, National Technical Information Service. TT 71-5100.

Hill, Jerry D. 1974. The Use of a 2-Layer Model to Estimate Soil Moisture Conditions in Kentucky. Monthly Weather Review, Vol. 102, No. 10, October 1974. pp 726-730.

Palmer, Wayne C. 1968. Keeping Track of Crop Moisture Conditions Nationwide: The New Crop Moisture Index. Weatherwise. August 1968. pp 156-161.

PART 2.0 FUNCTIONS OF MOISTURE STRESS

2.1 MAJOR VARIABLES

The stress degree is dependent on three variables at the time of occurrance - phenological growth stage, available soil moisture and temperature.

2.2 PHENOLOGICAL GROWTH STAGE

The Robertson Biometerological Time Scale phenological growth stages (reference 1) are used in the model as defined below and further described in Figure 1.

ROBERTSON'S BMTS	PHENOLOGICAL GROWTH STAGES
0.0	Planting
1.0	Emergence
1.5	Tillering
2.0	Jointing
2.5	Flag Leaf
3.0	Heading
3.5	Milk
4.0	Dough
5.0	Ripe

During each of these stages there are optimum conditions as well as unfavorable conditions for wheat growth. Most of these conditions are directly related to meteorological factors.

Various wheat stress conditions have been defined in the research papers (reference 2 and 3) that can be modeled. The stress conditions implemented in this first version of the model were the ones considered to have the most affect on the wheat growth cycle and for which input data are available from the limited weather data received by the CCAD at this time[1/]. Problem and optimal conditions that form the model logic are shown in Table 1 by growth stage. Additional factors will be integrated into the model in the future.

2.3 STRESS CONDITIONS BY GROWTH STAGE

A. <u>Growth Stage 0 - 1</u>. Planting requires at least 5 mm of moisture in the surface layer with the optimum being 15 mm in the surface layer. The germination (BMTS stage 0 - 1) of a wheat seed is effected by both moisture and temperature. At a temperature below 3°C and with a surface soil moisture content of less than 5 mm germination will

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[1/]The CCAD is provided meteorological information through the Joint Agriculture Weather Facility (JAWF). This meteorological data consists of minimum and maximum daily temperature and daily percepitation at this time.

FIGURE 1

BMTS and Phenological Growth Stages

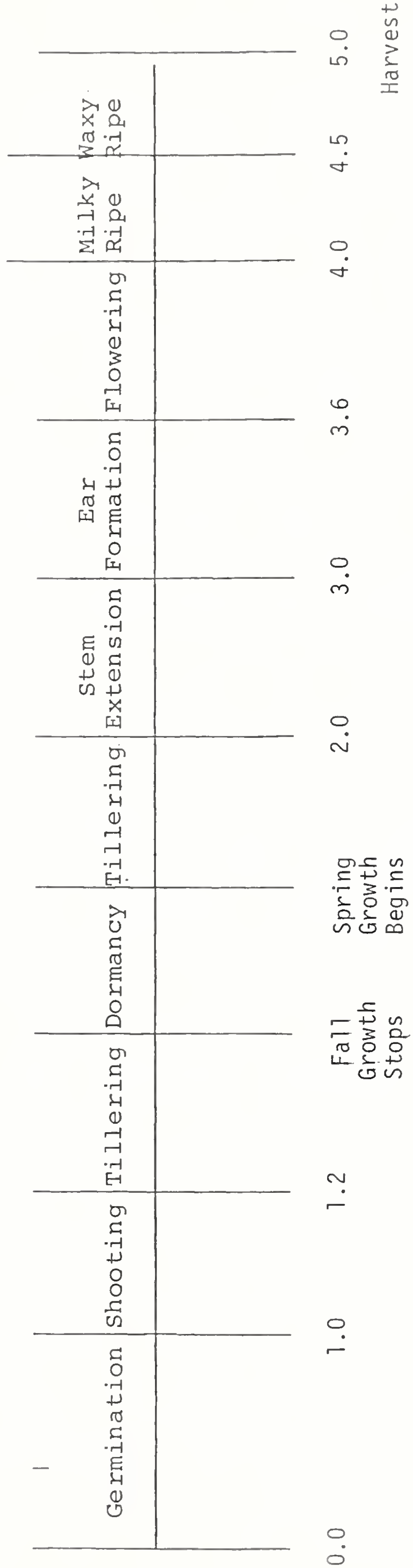

TABLE 1

BMTS	HAZARD CONDITION		OPTIMAL CONDITION	
0.0 - 1.0	Min Temp	$<3^{\circ}$ C	Min Temp	$>5^{\circ}$ C
	Surface Moisture	<5 mm	surface moisture	>15 mm
1.0 - 1.2	Min temp	$<-8^{0}$ C	Min Temp	$>5^{\circ}$ C
	Surface Moisture	<10 mm	FWC	>25%
1.2 - 2.0	FWC	<45%	FWC	>55%
2.0 - 3.0	Min Temp	$<-8^{\circ}$ C	Min Temp	$>5^{\circ}$ C
	FWC	<45%	FWC	>55%
3.0 - 3.6	Min Temp	$<-8^{\circ}$ C	Min Temp	$>5^{\circ}$ C
	Max Temp	$>42^{\circ}$ C	Max Temp	$<42^{\circ}$ C
	FWC	<45%	FWC	>60%
3.6 - 4.0	Min Temp	$<2^{\circ}$ C	Min Temp	$>5^{\circ}$ C
	Max Temp	$>42^{\circ}$ C	Max Temp	$<42^{\circ}$ C
	FWC	<25%	FWC	>40%
4.0 - 4.5	Min Temp	$<-8^{\circ}$ C	Min Temp	$>0^{\circ}$ C
	FWC	<10%	FWC	>40%

not take place. The optimum conditions for germination were found to be at a temperature of 25°C and with surface moisture content greater than 15 mm. At these optimum conditions germination will take place in 1 to 2 days. Without the proper temperature and moisture conditions germination will be delayed. The duration of the delay is determined by analysis of all conditions. Late germination of winter wheat may cause the plants to be more susceptible to winterkill.

B. Growth Stage 1.0 - 1.2. During the shooting period (BMTS 1.0 - 1.2) the plant may be destroyed if temperatures drop below -7°C while the optimum growth temperature during this growth stage is between 14°C and 25°C. Plant growth will stop at 5°C. The plant requires at least 10 mm of moisture in the surface layer with optimum being 25% of Available-water-holding-capacity (AWHC).[2]

C. Growth Stage 1.2 - 2.0. During the tillering stage (BMTS 1.2 - 2.0) the minimum moisture requirement is 45% of AWHC and an optimum moisture content of 55% of AWHC. During this growth stage the winter wheat plant stops growth (dormancy) for the winter.

Extreme cold and lack of snow can cause winterkill in the wheat; however, this event is not considered in this model since a winterkill indicator model was developed and is in operation during this period. When the temperature drops below 5°C, wheat growth stops and the plant is ready for wintering or dormancy. This period occurs at about growth stage BMTS 1.8 and lasts until the temperature rises above 5°C. Over this period of the winter the stress model only checks for sufficient soil moisture. The Winterkill Indicator Model runs during this period to detect potential winterkill. Shortly after spring growth starts, tillering is complete and wheat has reached growth stage 2.0 (BMTS).

D. Growth Stage 2.0 - 3.0. Stem extension (BMTS 2.0 - 3.0) is the next growth stage checked in the model. The plant is very hardy at this time and would require temperatures below -8°C to substantially damage the plant. However, less than 45% AWHC will adversely

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[2] Available-water-holding-capacity (AWHC) can be defined in laymans terms as the amount of water that a soil will hold that is available to the plant. The technical definition states the AWHC as the difference between the upper and lower limits of the moist soil-water state or the difference between the field capacity and the permanent wiliting percentage and is usually expressed on a volume basis when the bulk density is known. The concept of AWHC can apply to a horizon, layer or pedon. This can be expressed in terms of centimeters of water per specified depth of soil, as the two horizontal dimensions of the water and soil volumes are the same. Thus, the units of AWHC applied to characterize polypedons, or soil series are commonly expressed as centimeters (or inches) of available water per unit thickness (cm or inches) of soil, by horizon, or to the depth of rooting.

effect the growth and 60% AWHC is required for optimal growing conditions.

E. <u>Growth Stage 3.0 - 3.6</u>. During the ear or head formation stage (BMTS 3.0 - 3.6) temperatures above 42°C can cause unsatisfactory pollination and temperatures below -7% can destroy the plant. At least 45% AWHC is required during this period.

F. <u>Growth Stage 3.6 - 4.0</u>. The flowering stage (BMTS 3.6 - 4.0) freezing temperatures (0°C - -1°C) may sterilize the wheat and cause a complete crop failure. Lack of moisture during this period reduces the number of heads and number of grain or kernels per head. At least 45% AWHC is required during this period.

G. <u>Growth Stage 4.5 - 5.0</u>. During the waxy ripe stage (BMTS 4.5 - 5.0) plant requirements are minimal. Figure 1 shows the breakdown of each BMTS stage with the optimal and minimal condition requirements for winter wheat at each stage. Table 1 relates the BMTS to the crop stage.

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PART 3.0 WHEAT STRESS INDICATOR MODEL

3.1 MODEL COMPONENTS

The moisture stress model has as an integral part, a crop calendar model and a soil moisture model. Both of these models require daily minimum and maximum temperatures. The crop calendar model uses the Robertson Biometerological Time Scale (BMTS) (see reference 1) and the soil moisture model is the Two Layer or crop moisture index model (see references 4 and 5).

The crop calendar model requires actual or estimated planting dates. The crop calendar model used at the CCAD provides three biometeorological calendars based on percentage of the crop at a specific phenological growth stage at a given time, i.e. 15% emerged, 50% emerged and 85% emerged. However, only the 50% equivalent growth stage is used to provide information to the moisture stress model. Future developments/refinements may integrate the other two crop stage increments into the model.

The Two Layer Model required long term monthly historical mean temperatures, daily rainfall, daily mean temperature. In addition, an estimate of available water holding capacity of the various soils must be made to start the model.

For a more detailed description of these models refer to the Section 1.4, references 1 and 5.

3.2 STRUCTURE OF THE MODEL

The wheat stress indicator model was developed on a DEC 11/70 computer using FORTRAN IV language. The main inputs to the model are daily minimum and maximum temperatures from the meteorological station data, the daily growth stage from the crop calendar model, and the surface and subsurface moisture from the Two-Layer Soil Moisture Model. The crop calender model used is the Robertson Biometerological Time Scale Model and the soil moisture model is the Two-Layer Crop Index Model see (references 1 and 5).

3.3 MODEL PARAMETERS

The stress indicator model determines the possibility of wheat stress based on temperature and moisture conditions (see Table 1). The stress and optimal growth conditions are recorded for each growth stage as well as the total time the plant remained in these stages. From this information an analyst can judge the degree of damage or stress occurring at a growth stage and then determine the overall effect on crop development.

The output from the model is a record of each day that a stress condition has occurred, the reason for the stress and the crop growth stage. At the completion of processing data for a given meteorological station the data for that station are summarized giving the total days, optimum growth days and stress growth days.

3.4 TEST RESULTS

The test of the model is in the very early stages. Some comparison between 1977 and 1978 test runs in North Dakota have been completed with good results. During the next six months the model will be tested over various areas and the results analyzed. If weak areas are discovered in the model, corrective changes will be incorporated into future versions of the model.

PART 4.0 CONCLUSIONS

4.1 SUMMARY

A wheat soil moisture and temperature stress model was developed to support the Crop Condition Assessment Division of the Foreign Agriculture Service. The model is essentially a data filter that alerts a commodity analyst to areas that are under a potential stress condition due to adverse climatic conditions (soil moisture and temperature). The model was tested over sites in North Dakota using 1977 and 78 meteorological data. There was a dramatic difference in the model output for these two years. In 1978 the model reflected near optimium growing conditions during all growth stages, especially in the germination and emergence stage; whereas in 1977 the model indicated adverse conditions during all growth stages, especially the germination and emergence stage. The yield difference for the two years in the test area was 10 bu/acre or the 1977 yield was 40% below the 1978 yield. Additional pilot testing of this model will be conducted during the remainder of FY79.

To assess the potential impact of areas alerted by the model requires the analytical skills of a commodity analyst well versed in plant pathology, remote sensing, soils and meteorological data. Future improvements of this model are expected to be more sophisticated and reduce the analytical skills required at this time.